

An account of Sig. Schiapparelli's contributions will be found in *Les Mondes* for December, 1866; and the first quarter of 1867. An outline of them in English, from the pen of Professor Newton, will be found in the *Philosophical Magazine* for July, 1867, p. 34.

M. Le Verrier's communication was made to the French Academy of Sciences, and is published in the "Compte Rendu" of the 21st January, 1867, p. 94.

Mr. Stoney's paper will be found in the *Monthly Notices* of the Astronomical Society for June, 1867, p. 271; and in the *Philosophical Magazine* for September, 1867, p. 188.

XXX.—*On the Depths of the Sea.* By PROFESSOR WYVILLE THOMSON, LL. D., F. R. S. E., F. G. S., being the substance of a Lecture delivered on the 10th of April, 1869.

IN the year 1864, and in succeeding years, G. O. Sars, a distinguished son of the veteran and very distinguished Professor of Zoology in the University of Christiania, was employed as a Commissioner of Fisheries in the service of the Swedish Government; and in his official capacity he had an opportunity of dredging in deep water (300 fathoms) off the Loffoten Islands, within the Arctic Circle. Instead of finding the bottom of the sea barren at these great depths, as many circumstances had led many of our most able naturalists to anticipate; he brought up a multitude of animal forms, all of them of the highest interest both from their biological and their geological relations; and many were new to science.

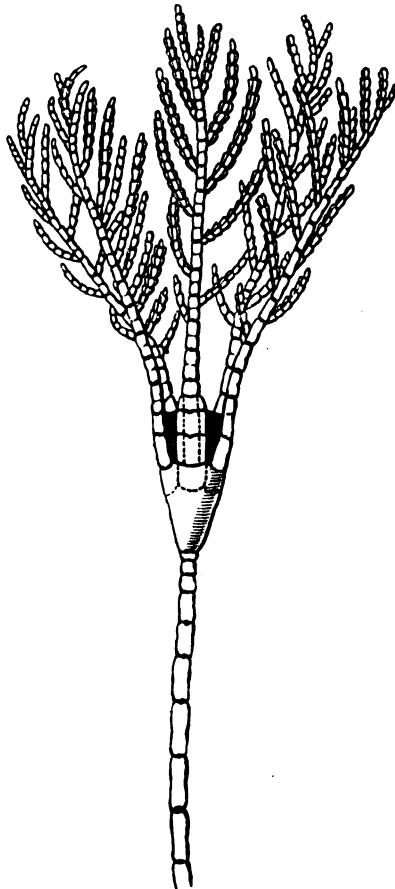
One animal form, of which about seventy specimens were found, was of surpassing interest. It was a "Crinoid"—a stalked starfish, with a delicate threadlike stem three or four inches long, and a head at first sight very closely resembling that of the pentacrinoid larval stage of a feather-star which is common in deep water off the Norwegian coast. A careful examination, however, showed that the crinoid was mature, and that it belonged to a totally distinct family of the order, hitherto only known fossil, and supposed to be almost entirely confined to the Mesozoic series of beds. This family is called the Apio-crinidæ, from the characteristic genus *Apio-crinus*, of which the species best known in this country is the "pear encrinite," which was got in great abundance in a bed of Great Oolite, exposed in cutting the tunnel through Box Hill. The group seems to have attained its maximum during the period of the deposition of the oolitic beds in the European area. It is not represented in the earlier formations, but we find handsome, well-developed species belonging to several genera in the Jurassic beds on the Continent. In the lower beds of the chalk there are two or three somewhat obscure forms, while in the white chalk the family, so far as we know, is represented by a single species of a single genus, Bour-

gueticrinus ellipticus, in which the head and arms are greatly reduced in size and development, the stem is much branched, and its joints are indefinitely and irregularly multiplied; which shows, in fact, all those peculiarities which we are accustomed to associate with comparative degradation in the animal scale. In the Tertiary formations there are only some obscure traces of one or two small forms of the group. Rhizocrinus Loffotensis of Sars stands in nearly the same relation to the Bourgueticrinus of the English chalk, in which Bourgueticrinus stands to the Apicrinites and Millericrinites of the Oolite. It is much smaller; the stem is even larger in proportion to the cup and special organs of nutrition; and here alone among known Crinoids we meet with a character which would indicate marked degradation—an irregularity in the number of the arms, of which there are sometimes four, sometimes five, and sometimes even six. It looks like a Bourgueticrinus which had been going to the bad for a million of ages; which was somehow getting worsted in the "struggle for life."

Rhizocrinus seems to be very generally distributed; Dr. Carpenter and I dredged it last summer off the north of Scotland, and about the same time Count Pourtales, who was investigating the opposite border of the Gulf Stream in connexion with the American Coast Survey, found it off the reefs of Florida.

Two living stalked Crinoids are well known inhabiting deep water in the sea of the Antilles, and apparently some other localities in the

Fig. 1.



RHIZOCRINUS LOFFOTENSIS (SARS.)  
(Four times the natural size.)

Indian and Australian seas; but they belong to a parallel family, which has come down continuously, usually represented by only a few species, from the period of the deposition of the English Lias. The remarkable point is the discovery of a representative, living at great depths in modern seas, of a family which had dwindled away, and apparently become almost extinct before the formation of the older Tertiaries. No discovery in natural science so suggestive as that of young Sars had been made for many long years; it set many of us pondering on the distribution and conditions of life in the depths of the sea.

The questions involved are very complicated. The late Professor Edward Forbes was the great authority on the distribution of marine life; he and his friend the late Dr. Robert Ball initiated the use of the dredge, and Forbes defined certain zones of depth which he held to be inhabited by special and characteristic groups of animals. The last of these was the abyssal or deep-sea zone, and he supposed that in this zone, which extended downwards from the 100-fathom line, life gradually became more and more scarce, till, at a depth of about 300 fathoms, it altogether ceased. Forbes' experience was much wider than that of any other naturalist of his time; the practical difficulties in the way of testing his conclusions were great, and they were accepted generally by naturalists without question. There was, besides, a popular impression that the conditions a mile beneath the surface of the sea must be so very peculiar, as to make it difficult to conceive that animals, more or less nearly related to forms inhabiting the upper world, could exist there; accordingly no attempt was made to dredge at great depths, except on the Scandinavian coast, and the results of the scattered observations made there have only appeared within the last few years. Except in one or two cases which never became very generally known, all the few creatures which came up to protest against Forbes' theory, came clinging to sounding lines, and were valueless for absolute proof; as their mode of capture constantly involved the question, which at that time we were unable to answer, whether there might not be pelagic forms of the groups to which they belonged.

In the year 1860 H. M. S. "Bulldog" sounded over the Atlantic plateau, and shortly after her return Dr. Wallich, the surgeon-naturalist who accompanied her, published a warm and able defence of the bottom of the sea as an inhabited region. The evidence of the existence of highly organized forms at great depths was not even yet however quite conclusive, as it still depended on star-fishes clinging to lead-lines, and although, from want of data, the subject was little discussed, the feeling of naturalists seemed still to be in favour of Forbes' "Zero of Animal Life."

#### THE CRUISE OF THE "LIGHTNING."

About the time of Sars' explorations in Loffoten, my friend Dr. Carpenter and I were engaged in some investigations which made the discovery of *Rhizocrinus* especially interesting to us, and we talked over, again and again, the curious questions, both geological and biological,

which Sars' dredgings suggested. We finally arranged that I should write a letter to Dr. Carpenter, who was then Vice-President of the Royal Society, sketching out what I conceived to be a promising line of inquiry, indicating generally the results which I anticipated, and urging him to endeavour to induce the Council of the Royal Society to apply to the Admiralty for a vessel fitted with dredging gear, that among other questions, the question of deep-sea life might if possible be settled definitely; by bringing up a quantity of the bottom, with its inhabitants, if there were any, along with it. The Council of the Royal Society acceded to Dr. Carpenter's request, and the Admiralty most liberally placed the surveying gunboat "Lightning" at their disposal, under the able and genial command of Staff Commander May. On the 11th of August last Dr. Carpenter and I left Stornoway, and steamed northwards towards the Faroe Islands. We had shocking weather—indeed during the whole of the cruise, which lasted nearly six weeks, we could only use the dredge on nine days, and only on four in deep water. We dredged a little on the Faroe banks, with small results, and on the 17th of August we reached Thorshaven, the capital of the Faroe Islands. We spent several days exploring the Fjords of that hospitable but hazy land, where it seems never to be afternoon, but always grey misty morning or night. On the 26th we left Thorshaven, and were driven by dirty weather to the south-eastward. This was perhaps fortunate, for it forced us to examine more carefully than we might otherwise have done the "cold area," to be mentioned hereafter, where the bottom was of stones and coarse sand, where the thermometer registered a minimum of 32° F., and where the fauna consisted of a meagre sprinkling of boreal and arctic forms. On the 4th of September we dredged in 530 fathoms, the thermometers registering a minimum of 47·5° F., and brought up a mass of fine, grey, slimy mud, technically called "ooze;" but which I shall now call "chalk-mud." We traced the area having this high temperature, which we may call the "gulf-stream area," southwards and westwards, in a line between the plateau of the Faroes and the north coast of Scotland, and Dr. Carpenter afterwards followed it as far north as lat. 61°. It is to this area and its geological and biological relations, that I wish specially to direct your attention.

#### CHALK-MUD AND CHALK.

During the last twenty or thirty years, very great improvements have been made in sounding apparatus, so that depths can now, as a general rule, be ascertained with a tolerable amount of precision. By two or three very ingenious contrivances, cups-ful, or little buckets-ful of the bottom may be brought up by the sounding line; one of these, contrived by Lieutenant Fitzgerald, R. N., which we used in the "Lightning," is exceedingly clever; I never knew it to fail. The laying of the cable directed special attention to the sounding of the North Atlantic; and in 1857, Captain Dayman; and in 1860, Sir Leopold M'Clintock accompanied by Dr. Wallich; and afterwards several others, sounded the area, and brought home what specimens of the bottom they

could procure. The result of the sounding was the definition of the great Telegraph plateau, stretching from Valentia nearly to Newfoundland, with an average depth of 2000 fathoms, with greatly deeper depths extending southwards towards the Azores. The result of the examination of the soundings was, that the bottom in all cases consisted of a fine calcareous mud; of countless myriads of the shells of a Rhizopod, Globigerina; and of some very peculiar bodies, which have been called Cocoliths and Cocospheres. In the meantime, naturalists were examining the microscopic structure of the white chalk, and they found it to consist of fine calcareous particles, Globigerinae and other foraminifera, and Cocoliths and Cocospheres. The structure of the chalk was, in fact, identical with that of the chalk-mud of the Atlantic. One might have thought that these deep sea soundings should have settled the question of the existence of life in the depths of the ocean, but they were all open to the objection that the Globigerinae and other organisms could not be shown to be absolutely living, and it was conceivable that they might have lived nearer the surface, and have sunk to the bottom after death.

All over the "warm area," our dredge brought up little else than the globigerina mud; not now, however, pure. The dredge brought up about a hundred weight at a haul. On one occasion a little way to the south of the Faroes, it brought up, mixed with the mud, about forty sponges—living—with the delicate and exquisitely-formed spicules suspended in the transparent sarcode. Most of these sponges had long and venerable beards of flint, spreading in all directions through the chalk-mud. These beards brought up, entangled in them, small clams, starfishes, and minute crustaceans; and among the mud were scattered the shells of the beautiful and well-known Pteropods of the Gulf Stream.

There can be no doubt whatever—indeed it is admitted by all microscopists—that chalk is now being formed in the depths of the Atlantic; but an idea which suggested itself to us even before we proposed our cruise has now ripened into a conviction, that it is not only chalk which is being formed, but THE CHALK—the chalk of the Cretaceous Period. There is one abyss in the Atlantic, in which the Himalaya mountains might lie, with the waves rolling over them unbroken; and there is no direct evidence that oscillations have taken place in the north of Europe or in North America, since the deposition of the earlier tertiaries, beyond 1500 feet; in fact there is a very strong presumption that the main features of the contour of the crust of the earth have altered but little since the commencement of the Mesozoic period, and that the great depressions, the Atlantic, the Pacific, and the Antarctic Oceans, are due to causes which acted even before that very remote epoch. There have been constant minor oscillations; but the beds formed during the periods of depression, and now exposed by an upheaval of this minor character; are all comparatively local and shallow-water beds, as shown by the nature and the richness of their faunae. To put this in another form; there is no reason to suppose that either the

physical or the biological conditions of two-thirds of the ocean have been affected by the oscillations which produced the varying distribution of the sea and land, and the local modifications and migrations of faunae during the Tertiary period. No doubt the temperature of the different portions of the deep sea has altered again and again, owing to geographical changes influencing the distribution of the minor currents and the branches of the great currents; and it is to the accumulation of these slight changes through countless ages that we must look as the cause of the gradual modification of the fauna of the chalk; of the extinction of some animal groups, and the greater development of others. A bit of the edge of the Cretaceous formation has been tilted up, to form the white cliffs of Albion and the chalk beds of France; but the great mass of the formation maintains nearly the same character, and is now entombing the same groups of organisms, among the Philippines, off the coast of Spain, in the seas of Japan, near the coast of Massachusetts, off the Faroes, and to the extreme Loffoten Islands. I imagine that this is one of the GREAT FORMATIONS,—one of the corner stones in the building of the earth; formed slowly in vast areas of subsidence; which will only make its appearance in mass along with a complete change in the distribution of land and sea; and which may be expected in some places to resist denudation, and to stand like the mountain limestone, as one of the odd pages of a future geological record. Some great peculiarities in the distribution of the miocene land-flora have led to the idea that one of these minor oscillations may have depressed the "Telegraph Plateau" during later Tertiary times. It may be so, though I think the evidence is very unsatisfactory; but it is by no means necessary that every part of the present Cretaceous basin should have been sea throughout; whenever it was sea, however, it was continuous in space with a sea which had been continuous in time—probably, at all events, from the commencement of the Jurassic period; and was peopled from that sea. If these views prove correct, they must modify considerably our interpretation of geological history.

#### CHALK FLINTS.

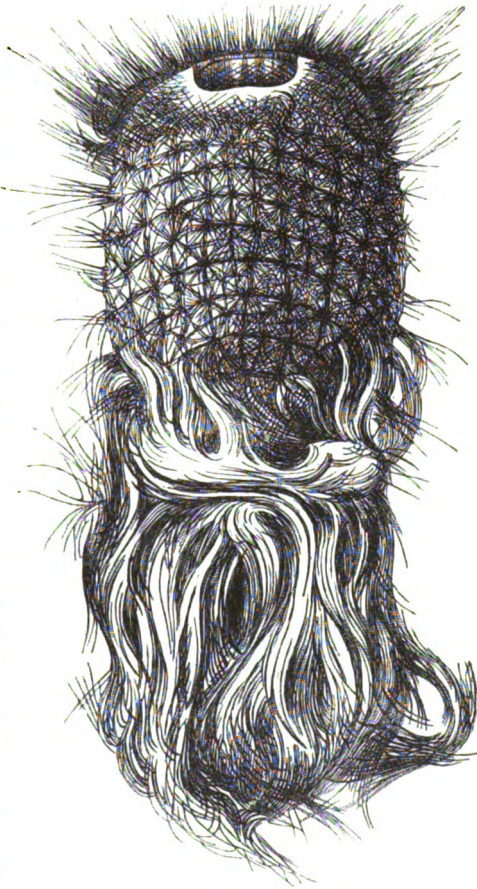
There is one point, in the structure and composition of the white chalk, which distinguishes it, in the most marked way, from the modern deposits of the Atlantic. Modern soundings and dredgings from all depths, are full of delicate siliceous organisms of the most varied and beautiful forms. Shields of diatoms, spicules of sponges, and the wonderful netted skeletons of the polycystina. The soft calcareous mud is the home of multitudes of exquisitely-formed glassy and other siliceous sponges; the chalk, on the other hand, may be said to contain no disseminated silica whatever. When chalk is dissolved in acid, a few grains or crystalline fragments of silica remain; but these are apparently all of inorganic origin—fragments of mineral matter. Instead, however, of disseminated siliceous organisms, we have, in the chalk, bands and lines of flints; lumps of amorphous silica, which seem to have filled up and taken the shape of any cavities already existing in the beds. Many

of these flints are apparently quite shapeless, but many of them, such as the so-called "paramondras" of the Antrim chalk, have, more or less distinctly, the form of large cup-like sponges. Often the shell of a sea-urchin forms the mould of a flint, which fills it entirely, reproducing in relief on its external surface every suture and perforation of the inner surface of the shell. The conclusion seems to be irresistible, that in some way, which we do not as yet thoroughly understand, but to which some late observations of the Master of the Mint seem to promise a clue, the organic silica, if I may use the expression, is dissolved out of the calcareous matrix; the solution percolates into and through the cavities, the water being gradually drained from the silica, which is in the colloid state, by the walls of the cavities acting as porous media; till, on the water being nearly or entirely removed, the silica "sets" into flint. In the white chalk of England there is an exceedingly beautiful group of fossils, called *Ventriculites*, which have greatly puzzled paleontologists. They have usually the form of graceful vases, tubes, or funnels; variously ridged or grooved, or otherwise ornamented on the surface; frequently expanded above into a cup-like lip, and continued below into a bundle of fibrous roots. The minute structure of these bodies shows an extremely delicate tracery of fine tubes, sometimes empty, sometimes filled with loose calcareous matter, dyed with per-oxide of iron. We have been in the habit of regarding the *ventriculites* as an extinct group, specially characteristic of the chalk; but after examining several species, and studying carefully Mr. Toulmin Smith's excellent observations on their structure, I now thoroughly believe that they were siliceous sponges, nearly allied to, if not identical with, the recent order, *PORIFERA VITREA*; and that the silica of their spicules was removed, and went to add to the jelly-like material of the flints, leaving the moulds only in the chalk. *Ventriculites* are not extremely common in the white chalk, nor are they very large; and so far from being extinct, my belief is that the group has attained probably a much higher development in our times; that while the pear-encrinites have been losing ground, the *ventriculites* have been gaining it. One haul of our dredge in the soft, warm, oozy, chalk-mud off the north of Scotland, brought up from a depth of 500 fathoms upwards of forty specimens of vitreous sponges. Many of these were new to science, and some of them resembled closely the beautiful *Venus'* flower-basket of the Philippines, while among them were probably two species of *Hyalonema*, the strange glass-rope sponge of Japan. Four specimens of this wonderful new form of vitreous sponge, which I exhibit (see wood-cut), were brought up in this haul. They were loaded with their glairy sarcode, and had evidently been buried in the ooze nearly to the lip. When one looks at the exquisite symmetry of these organisms, one almost wonders at the recklessness of beauty, which produces such structures to live and die for ever invisible, in the mud and darkness of the abysses of the sea. I dedicate, with great pleasure, the new genus to which this sponge must be referred, to our kind and hospitable friend, his Excellency M. Holten, the Governor of the Faroe Islands, who

showed the greatest interest in the success of our expedition, and on the verge of whose dominions it was found. I dedicate the species to my colleague, Dr. Carpenter.

The mud was entirely filled with the delicate siliceous root fibres of the vitreous sponges, binding it together, and traversing it in all directions like hairs in mortar. This mud was actually alive; it stuck together in lumps, as if there were white of egg mixed with it, and the glairy mass proved, under the microscope, to be living sarcode. Prof. Huxley regards this as a distinct creature, and calls it "Bathybius." I think this requires confirmation. Every fibre and spicule of each sponge has its own special sheath of sarcode, and the glairy matter in the mud may, I think, be simply a sort of diffused mycelium of the different distinct sponges. This view accords well, I believe, with the mode of nutrition of the sponges.

Fig 2.



HOLTENIA CARPENTERI (WY. T.)  
(Half the natural size.)

**THE CONDITIONS OF THE DEPTHS.—PRESSURE.**

The conditions which might be expected to affect animal life at great depths in the ocean are pressure; temperature; and the absence of light, involving apparently the absence of vegetable food. The conditions of pressure are certainly very peculiar. A man at the depth of a mile would bear upon his body a weight equal to about ten ordinary goods trains, engines and all, loaded with pig iron. We are apt to forget, however, that water is nearly incompressible, and that, therefore, the sea water at the depth of a mile has scarcely an appreciably greater



density than it has at the surface. At the depth of a mile, under a pressure of 159 atmospheres, sea water, according to the formula given by Jamin, is compressed by the  $\frac{1}{11}$  of its volume; and at 20 miles, supposing the law of the compressibility of water to continue the same, by only  $\frac{1}{4}$  of its volume—that is to say, the volume at that depth will be still  $\frac{3}{4}$  of the volume of the same weight of water at the surface. Substances, also, permeated and uniformly supported within and without by the water, are, so far as their physical conditions, freedom of motion, &c., are concerned, in no way affected by the pressure. We sometimes rise in the morning, and find from a fall of an inch in the barometer, that we have been gradually and quietly relieved during the night of half a ton weight; yet we feel it only by a slight lassitude, from its requiring rather more muscular exertion to move our bodies in the rarer medium. There is no reason to believe that water contains less air at great depths than at the surface; it is even possible, owing to the great compressibility of air, that it may contain more. As the increase in the density of the water at the depths at which we dredged was scarcely perceptible, we found no inconvenience at all from the pressure, except in one particular. The strong tarred hemp rope which we used belonged to the upper world, and, like all such terrestrial fabrics, it contained a large quantity of air. Down in the depths every particle of the air was squeezed out, and the fibres of the hemp and the tar were crushed together, so that the rope looked and cut almost like a stick of liquorice. I fear the rope became rather brittle, for it snapped once or twice without apparent cause, and we lost our dredges. This may turn out to be a serious difficulty in the way of dredging in much greater depths.

#### TEMPERATURE.

There has been up to the present time a strange misconception as to the temperature of the ocean—a misconception all the more singular as it is a point easy of approximate determination, and to which a good deal of attention has been directed. In all the leading text books on physical geography we have the reiterated statement that at a certain depth the ocean has a uniform temperature of 39° F.; that the ocean is, therefore, divided into three regions, bounded by the two Isotherms of 39° F.; that north and south of these lines the mean temperature of the surface is lower than that of the depths, while in the zone between them it is higher. Had the sea been fresh, it would have been perfectly intelligible that the water beyond the influence of currents and of direct solar heat, should have maintained the temperature of its point of greatest density; but it has long been well known, from the experiments of M. Depretz and others, that sea water contracts steadily down to its freezing point, which is about 28° F. when agitated, and as low as 25° F. when perfectly still.

Though I had often wondered what could be the cause, I believed in this permanent temperature of the sea thoroughly; and even suggested the particular course for our cruise, because it nearly coincided with the Isotherm of 40° F., expecting that we should be able

within a few hundred feet of the surface, to eliminate the question of heat entirely from our calculations. To our very great surprise, the thermometers, two of which were sent down on the lead-line the day after we left Stornoway, to a depth of 500 fathoms, registered a minimum temperature of  $49^{\circ}$ , ten degrees *above* the "permanent point." We were at first inclined to mistrust the observation; but we took the same temperature at nearly the same spot on our return, when we were quite prepared to recognize it as the almost constant temperature of the warm, or Gulf Stream area of the region. Some days later, on leaving Thorshaven, and proceeding south-eastwards, we sounded, and took temperatures with three registering thermometers, in 510 fathoms, in lat.  $60^{\circ} 45' N.$  and long.  $4^{\circ} 19' W.$ ; when the three thermometers, which were within about  $2^{\circ}$  of one another, gave a mean result of  $32.2^{\circ}$ ; almost exactly the freezing point of fresh water, and more than  $7^{\circ}$  *below* the "permanent point." Many subsequent observations enabled us to determine that a cold area, where the thermometer ranged about  $32^{\circ} F.$ , at a depth of from 4 to 500 fathoms, extended between lat.  $60^{\circ}$  and  $61^{\circ} N.$ , and long.  $4^{\circ} 30'$  and  $7^{\circ} 30' W.$ ; and that an area stretched north-westward, westward, and south-westward of this cold area; in which the thermometer, to the depth of 650 fathoms, was very permanent at  $47.5^{\circ}$  to  $49^{\circ} F.$  This is an unexpected result; but it is undoubtedly in the main correct. The soundings were made with the greatest care and with the best instruments, and several thermometers by different makers were employed on every occasion, every precaution being taken to avoid error.

Since the Gulf Stream, to which we attribute the warmth of the warm area, appears to affect the temperature of the sea to the very bottom, it is easy enough to conceive that the temperature may be permanent over a considerable region at  $49^{\circ}$ ; but it is not so evident why the temperature of the cold area should remain permanently two or three degrees above the freezing point of salt water. It is possible that the freezing point may be the actual limit, and that the Sixes thermometers, which have large bulbs, register a degree or two too high, under the enormous pressure of 100 atmospheres. If this be the case, the condition of things must be very peculiar. Minute spicules of light fresh ice must be continually forming, and rushing upwards to be melted in the first shell of water whose temperature is above the freezing point. The animal inhabitants must live in perpetual winter—a winter not more severe, however, than that which is bravely borne by the myriads of limacinas and clios which sport in every crack in the ice fields of the Arctic sea.

NUTRITION.

The question of the mode of nutrition and life of animals at these great depths is a very singular one. The practical distinction between plants and animals is, that plants prepare the food of animals by decomposing certain inorganic substances which animals cannot use as food, and recombining their elements into organic compounds upon which animals can feed. This process is, however, constantly effected

under the influence of light. There is little or no light in the depths, and naturally there are no plants : but the bottom of the sea is a mass of animal life. On what do these animals feed ? The answer seems to be sufficiently simple : nearly all the animals—practically *all* the animals, for the small number of higher forms feed upon these—belong to one sub-kingdom, the Protozoa, whose distinctive character is that they have no special organs of nutrition, but that they absorb nourishment through the whole surface of their jelly-like bodies. Most of these animals secrete exquisitely-formed skeletons, sometimes of lime, sometimes of silica. There is no doubt that they extract both of these substances from the sea water, although silica often exists there in quantity so small as to elude detection by chemical tests. All sea water contains a certain quantity of organic matter in solution. Its sources are obvious. All rivers contain a large quantity : every shore is surrounded by a fringe which averages about a mile in width of olive and red sea-weeds : in the middle of the Atlantic there is a marine meadow, the Sargasso Sea, extending over three millions of square miles : the sea is full of animals which are constantly dying and decaying ; and the water of the Gulf Stream, especially, courses round coasts where the supply of organic matter is enormous. It is, therefore, quite intelligible that a world of animals should live in these dark abysses, but it is a necessary condition that they should chiefly belong to a class capable of being supported by absorption through the surface, of matter in solution ; developing but little heat ; and incurring a very small amount of waste by any manifestation of vital activity. According to this view, it seems highly probable that at all periods of the earth's history, some form of the Protozoa, rhizopods, sponges, or both, predominated greatly over all other forms of animal life in the depths of the warmer regions of the sea ; whether spreading, compact, and reef-like, as the Laurentian and Palæozoic coozon ; or in the form of myriads of separate organisms, as the globigerinæ and ventriculites of the chalk. The rhizopods, like the corals of a shallower zone, form huge accumulations of carbonate of lime, and it is probably to their agency that we must refer most of those great bands of limestone which have resisted time and change, and which come in here and there with their rich imbedded lettering, to mark, like milestones, the progress of the passing ages.

